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RAPID REPORT

Laser Treatment of Solar Elastosis With Epithelial Preservation

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Background and Objective: **Laser resurfacing has gained wide acceptance for the treatment of actinic facial skin. However, postoperative care of the face is reasonably complicated and prolonged erythema is common. To simplify the postoperative care and to possibly reduce the duration of the erythema, we investigated a laser treatment that spares the epithelium.**
Study Design/Materials and Methods: **A 980 nm diode laser was used with a spherical optic handpiece to focus the light in the dermis. We treated in vitro breast and facial skin and measured the tissue shrinkage and the histological changes. We also treated two patients and harvested the tissue after 6 and 21 days of wound healing.**
Results: **The diode laser treatment does not ablate the epidermis. The tissue shows shrinkage (16% at 8W) similar to three passes of the scanned carbon dioxide laser treatment (15%). Thermal damage in the dermis is similar to the residual damage left after laser resurfacing with the scanned carbon dioxide laser. After 21 days the tissue shows new collagen and an abundance of young elastin fibers.**
Conclusions: **These investigations indicate that solar elastosis in skin can be treated with the 980 nm diode laser while preserving the epithelial layer. Lasers Surg. Med. 23:121–127, 1998.** **© 1998 Wiley-Liss, Inc.**

Key words: diode laser; cutaneous; contact handpiece; histology; collagen shrinkage

INTRODUCTION

Cutaneous carbon dioxide laser resurfacing has gained wide acceptance for the treatment of actinic facial skin. Rhytidectomy remains the treatment of choice for redundant, sagging tissue, and excess subcutaneous fat [1,2]. However, multiple fine and medium wrinkles, especially in the periocular and perioral regions, respond better to resurfacing techniques. The laser is preferred over dermabrasion and chemical peels because of the ability to precisely control the level of damage with the laser [3,4]. Although the laser, when used appropriately, lessens the danger of hypertrophic scarring, there is still the possibility of producing prominent hypopigmentation, prolonged erythema, and irregular hyperpigmentation [5].

The resurfacing laser affects the skin by ablating the surface and leaving a bed of thermally damaged dermis [6]. The first pass of the re-

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surfacing laser typically removes the skin above the dermal—epidermal junction [7]. Subsequent passes remove the papillary dermis and part of the reticular dermis. The skin just below the ablation layer is thermally damaged, showing denatured collagen and coagulated blood vessels.

The remaining skin has been shown to undergo shrinkage immediately after resurfacing [7]. This shrinkage has been shown to persist well into the healing phases of the skin [8]. It is believed that the thermally denature collagen is responsible for the initial shrinkage. One might conjecture that this contracted collagen serves as a "scaffolding" or "template" for the healing process. Using the template, the new external layers of skin preserve this shrinkage.

Postoperative care of the face is reasonably complicated, requiring both the avoidance of sunlight and dressings, which must be changed frequently, to keep the wound bed clean and moist [9]. The exact prescription for postoperative care varies greatly with the attending physician. At least one study has shown no affect on wound healing in a porcine model related to variations in the elements of a postoperative care regimen [10]. Other studies have shown that topical applications of L-ascorbic acid can act as an anti-inflammatory agent and decreases the amount and duration of erythema [11].

Ideally, one would like to thermally denature and shrink the collagen within the dermis without destroying the epidermis. In this way, the epidermis will protect the damaged dermis, thereby eliminating the need for dressings. Wound healing can also progress much quicker without having to wait for the reepithelialization in the early phases of wound healing seen with conventional ablative modalities. The same wound repair process that leads to softer and younger appearing skin would also take place. Thus, the solar elastosis of the dermis could be corrected while sparing the epithelium.

To affect such a thermal wound, different techniques have been attempted. In some studies the surface of the skin is cooled just before the laser pulse with a short burst of a refrigerant [12]. It has been argued that the refrigerant cannot sufficiently cool the epidermis to avoid damage. If the epidermis is cooled too much, it can be damaged by ice forming in the cells. Research to cool the tissue enough to prevent thermal damage and to prevent cell death from too much cooling is progressing.

We have taken a different approach to spare the epithelium during these laser procedures. We have developed a system that delivers the laser energy over a relatively large area. The laser light is focused in the dermis. The optical device that focuses the laser light also acts as a thermal conductor on the surface to help conduct away any heat in the epithelium before cell damage occurs. Additionally, air is flowed over the conductor and the skin surface to maintain a minimal temperature increase at the surface. The laser wavelength has been selected to allow relatively deep penetration into the dermis.

Three factors control and limit the depth of thermal damage. They are the wavelength, the pulse length, and the focal characteristics of the light. Later we explain how each of these parameters is used.

MATERIALS AND METHODS

Laser

The laser is a 25 W diode laser (SkinLaser, BioLase Technology, Inc. San Clemente, CA) delivered through a 600 μm fiber delivery system. The laser is fired in a single pulse mode. Repeat pulses are affected by stepping on the foot pedal multiple times, however an automatic repeat mode is available. Thus, pulses can be repeated at approximately 2 Hz (up to 10 Hz in the automatic mode). Typically, a repeat pulse frequency of approximately 1Hz is used. The laser is used at 6 to 24 W with 400 msec pulse durations. The wavelength is 980 nm. The fiber delivery system includes a multilumen jacket containing a large core fused silica fiber optic terminating at the distal end with a proprietary handpiece (BioLase Technology, Inc., patent pending). The distal end of the fiber delivery system contains a handpiece by which laser energy is deposited into compressed tissue by way of a spherical optic. The spherical optic floats freely in an air bearing. The air acts as a coolant of both the optical train contained within the handpiece and the tissue under treatment. An annular space around the spherical optic is configured to direct the coolant directly to the treated tissue. No additional cooling of the tissue is required.

The optical train has been configured to deliver laser energy with a low contact-surface

power density and a short focal distance. Depending upon the target tissue and the desired endpoints, different distal-end configurations resulting in different optical characteristics have been developed. Three handpieces have been used in this study, a deep probe, a moderate probe, and a shallow probe.

Tissue Samples

In this study we used skin samples in vitro harvested from reduction mammoplasties. We also used eyelid and eyebrow skin obtained from blepharoplasties. In most cases the subcutaneous fat was excised and the skin was stored in iced sterile saline and used within 72 hours. Some tissue was stored for longer periods of time. This tissue was placed on saline moistened gauze, double wrapped in aluminum foil, and sealed in an airtight plastic bag and stored at 4°C for 2 days or less, or frozen at −20°C for extended storage. All tissue was used within 4 months of freezing.

Some of the procedures were performed on patient eyelids and eyebrows, in vivo, prior to blepharoplasty. On two patients, the skin was allowed to heal after the laser treatment for 2 or 6 weeks before blepharoplasty.

Shrinkage Measurements

Tissue shrinkage was evaluated by measuring the linear distance change between two marks of a surgical pen placed 1 to 2 cm apart on the tissue. To measure the distance, a video camera (Panasonic GP-KR222, Matsushita, Secaucus, NJ) was interfaced into a PC compatible, Windows based computer. Using imaging software (Laser Skin Toner, Rydal, PA) the surgical pen marks were identified by the user and the distance between the marks was measured by the computer. The image of the skin after laser treatment was captured again and the distance was determined in a similar manner. If multiple passes were performed, image capture occurred after each pass and the captured image was compared to the baseline. The computer then calculates the percentage change in the distance between the two marks.

Histology

Tissue samples after treatment or harvest (in the case of the healing studies), were fixed in 10% formalin. The samples were trimmed and embedded in paraffin, sectioned and stained with either hematoxylin and eosin, Masson's trichrome or Movat's stain for light microscopic evaluation.

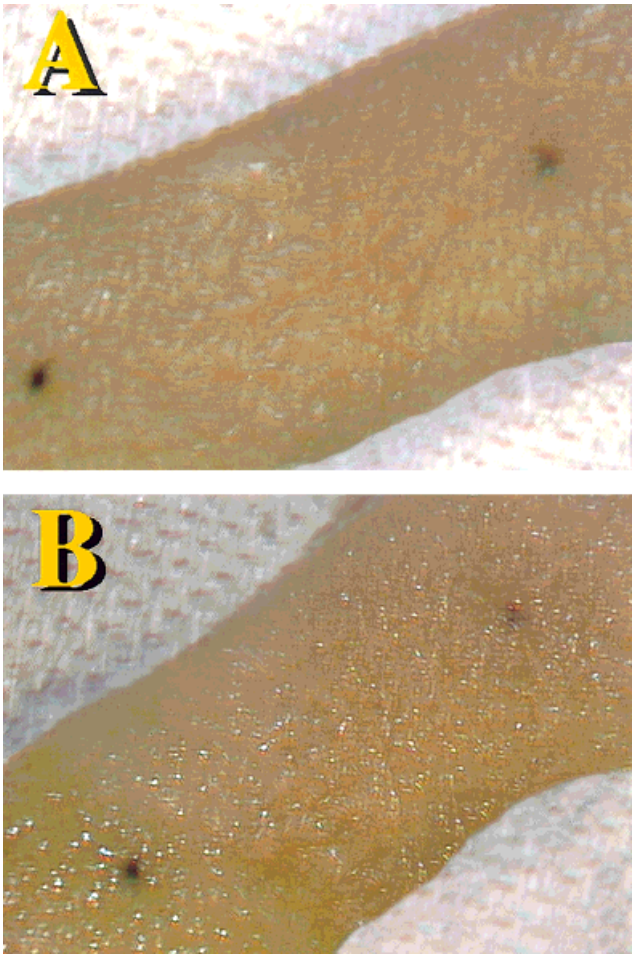

Fig. 1. **A.** Breast skin sample before irradiation. The two ink marks are used to measure the skin shrinkage. **B.** The same skin sample after treatment with the diode laser.

Analysis was performed on an Olympus Vanoz AH-2 microscope (Lake Success, NY). Morphometric analysis was performed with Southern Micro Instruments planar morphometry software (Atlanta, GA).

RESULTS

The treatment of the skin with the diode laser and handpiece showed no obvious signs of gross damage, except at the highest fluences. In Fig. 1, we show photographs of the tissue before and after treatment. The measurements of shrinkage with the shallow probe showed a mean of 2 ± 0.5 %/W shrinkage per treatment of the tissue. Using the laser at 8 W, this is a 16% shrinkage and is comparable to the carbon dioxide laser that has been reported to have 5% shrinkage per pass of the laser (15%

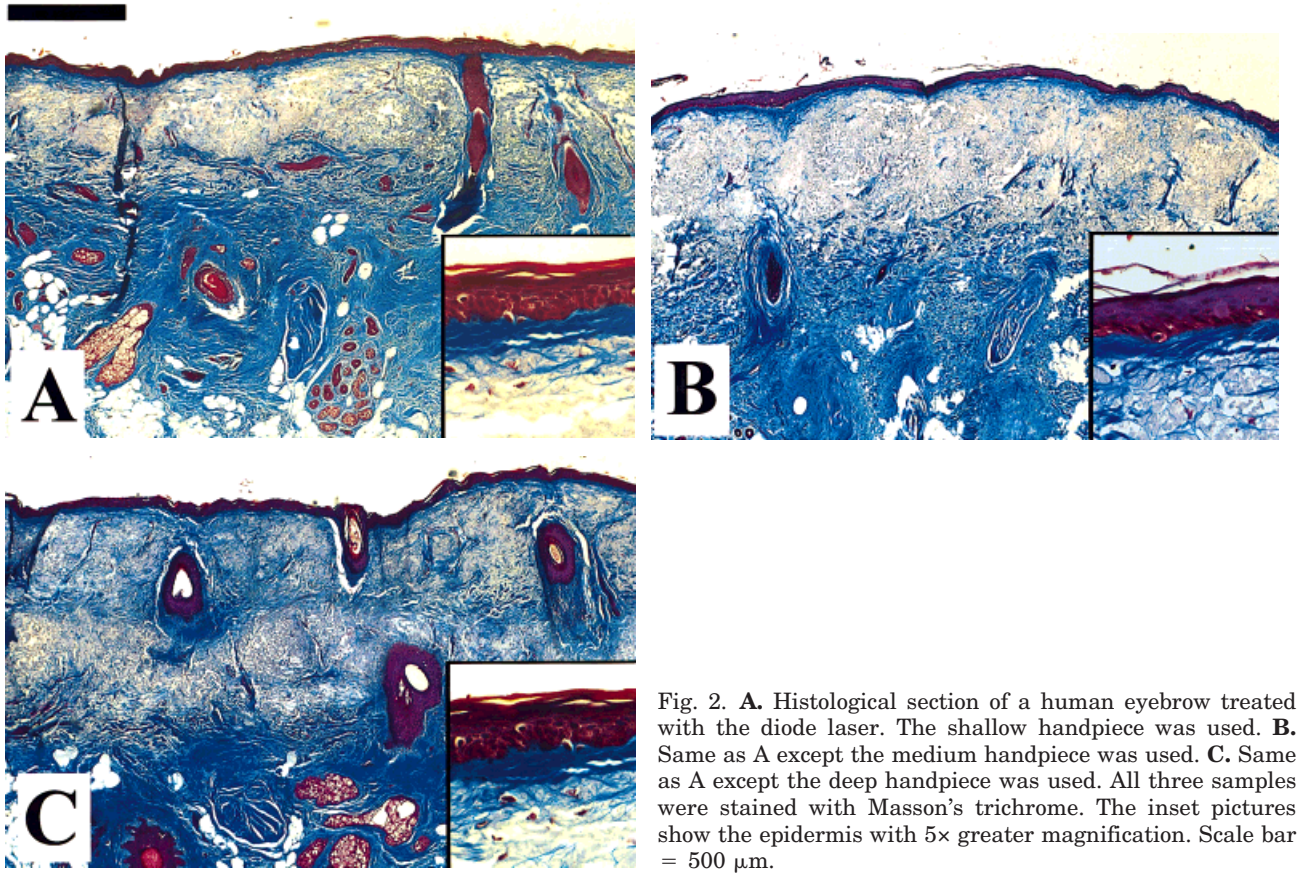

Fig. 2. **A.** Histological section of a human eyebrow treated with the diode laser. The shallow handpiece was used. **B.** Same as A except the medium handpiece was used. **C.** Same as A except the deep handpiece was used. All three samples were stained with Masson's trichrome. The inset pictures show the epidermis with 5× greater magnification. Scale bar = 500 μm.

shrinkage for 3 passes) [7]. Since tissue is not removed, the concept of "passes," as traditionally used with the carbon dioxide laser, does not apply. In some of our studies we would apply the laser with a matrix of approximately 5 mm between the application sites. We would then apply a second or third pass with the laser applying a similar matrix, slightly displaced.

The handpieces are single-use devices. Multiple use of the handpiece has resulted in instances of epithelial burns in pre-study trials. We used each one for no more than approximately 2000 pulses of the laser. The tip was cleaned of any debris during the laser treatment with an alcohol pad. Debris on the handpiece could be noted because the sphere would no longer freely roll over the tissue. Examination of the probes with microscopy and electron microscopy after use showed damage to the sphere in those instances where the debris was intentionally not cleaned off the sphere. Some debris was also noted around the spherical optic. When the handpiece was cleaned during the procedure, little damage of the optic was noted.

The histology of the treated skin showed a zone of denatured collagen under the epithelium of the tissue. The epithelium appears to be intact and healthy. At the highest fluences, damage to the epithelium was noted. In Fig. 2, we show a composite view of the histology from skin samples treated with the three different handpieces. The zone of thermal damage is given for the three handpieces in Table 1.

In the wound healing studies as shown in Fig. 3, the healing has progressed by day 6 (see Fig. 3A). There are few inflammatory cells noted at the wound site, and the denatured collagen appears to have been completely digested. Also present at the wound site is a modest amount of new collagen that has not completely reorganized. The epithelial layer remained intact and shows the presence of papillae. The wound is not distinguished at this date by the presence of sharply demarcated boundaries between the newly reorganizing collagen and the surrounding mature collagen. By day 21 (see Fig. 3B), the wound appears nearly normal with organized collagen bundles. The Movat's stain at day 21 (see Fig. 3C)

TABLE 1. Thermal Damage Zones for the Three Probes Used in This Study*

Probe	Distance from the surface to the start of thermal damage (microns)	Distance from the surface to the end of thermal damage (microns)	Laser operating range (W) 0.4 second pulses
Shallow	90 ± 40	750 ± 60	6–10
Moderate	90 ± 40	750 ± 90	14–18
Deep	140 ± 60	1475 ± 180	18–22

*Means plus standard deviations are given.

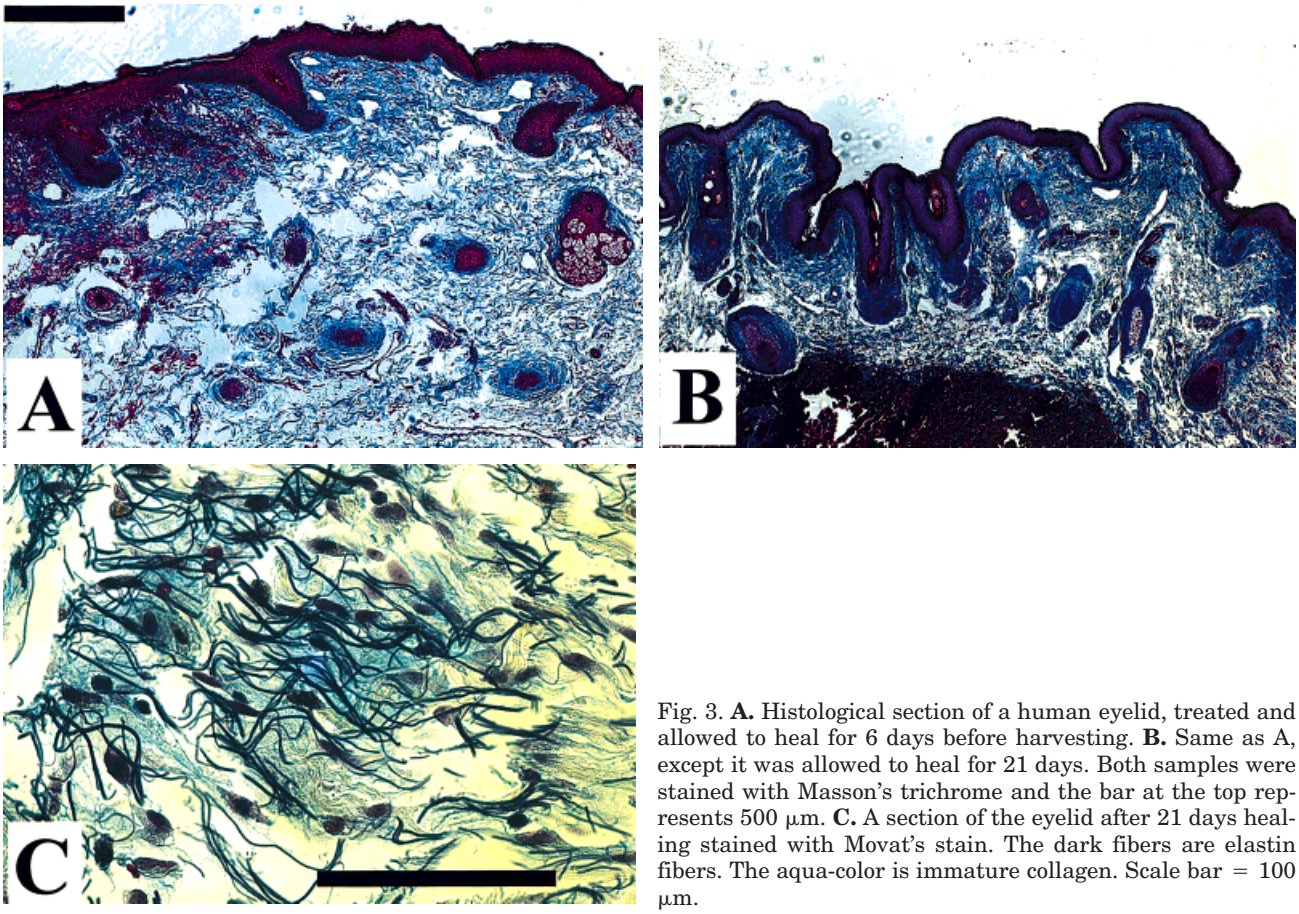

Fig. 3. **A.** Histological section of a human eyelid, treated and allowed to heal for 6 days before harvesting. **B.** Same as A, except it was allowed to heal for 21 days. Both samples were stained with Masson's trichrome and the bar at the top represents 500 μm. **C.** A section of the eyelid after 21 days healing stained with Movat's stain. The dark fibers are elastin fibers. The aqua-color is immature collagen. Scale bar = 100 μm.

shows elastin fibers among the collagen bundles, consistent with normal youthful skin.

DISCUSSION

The search for a more effective modality to treat facial wrinkles and photodamaged skin has led to an explosive growth in the popularity of laser skin resurfacing. We have investigated the use of 980 nm laser light from a diode laser and a unique handpiece to cause controlled collagen damage similar to that caused by the carbon dioxide laser but designed to also preserve the epithelial layer. The surface of the skin is preserved because the laser light is delivered over a large area of the tissue and the light is focused below the tissue surface. Also, the wavelength of light was selected to permit a deeper penetration than is possible with the carbon dioxide laser. Additionally, the final optical element of the laser delivery system is a spherical optic with air flow to dissipate heat.

The depth where the thermal injury starts can be regulated, within limits, by adjusting how far away from the sphere the light is focused. One can see from Table 1 that the thickness of preserved tissue is greater for the deep handpiece than for the moderate and shallow handpieces.

We did not measure any difference in the zones of thermal damage between the shallow and moderate handpieces. This is probably because the penetration distance of the light is much larger than the distance to the focal point for the moderate and shallow probes. Additionally, the 0.4 second exposure time allows for a large amount of thermal conduction during the laser exposure.

The depth of thermal damage, or the distance of the thermal damage from top to bottom is regulated by the wavelength of the laser and the absorption coefficient at that wavelength in addition to the focal distance of the handpiece. We see a change in the distance between the deep and the moderate probe. Again, no difference is again seen between the moderate and the shallow probes. At 980 nm, the major chromophores are hemoglobin and melanin. Additionally, water has a small absorption band that peaks near 980 nm [13]. Using longer wavelengths (up to 1100 nm) will show deeper penetration. As the wavelength increases in this range, all three chromophores decrease in absorption coefficient and scattering is reduced. Using shorter wavelengths within the visible range will decrease penetration. The hemoglobin and melanin absorption coefficients both increase, as does scattering. The additional scattering will make the intra-dermal focusing of the laser light more difficult, if not impossible. The backscatter will also increase the amount of damage in the epithelial layer. For these reasons, we chose 980 nm.

In many of the early studies, it was assumed that collateral thermal damage from the laser would denature the collagen and cause the tissue to shrink. This was quantitatively demonstrated. In a recent study, the amount of shrinkage was shown to be dependent upon the amount of tissue debridement [14]. Here we show tissue shrinkage similar to the carbon dioxide laser resurfacing. We do not use any debridement in these studies. In any event, if the tissue shrinkage serves as a scaffolding for the new collagen matrix in the wound repair process, the diode laser should show a reduction in rhytides similar to the carbon dioxide laser resurfacing.

The healing study at one week shows that the epithelium does not necrose and slough off a few days after the treatment. This would be possible and expected if the entire vascular supply was coagulated and blocked [15]. Although some small vessels are clearly coagulated in the histological sections, enough vessels must remain to allow the epithelium to survive. We speculate that more blood vessels could be preserved if the laser exposure time was decreased.

The 3 week healing study shows that the skin returns to a normal architecture with collagen bundles and elastin fibers. The skin treated in the wound healing experiment was particularly thin, and the wounds exhibited no complications. This is very encouraging. The skin also shows a slightly thicker band of collagen beneath the epidermis. This is similar to the results observed for carbon dioxide laser resurfacing [16]. The histological studies showed increases in the collagen layer thickness that persisted for one year following treatment.

The wound healing in these cases was done without dressings. This is not only easier for the patient, but should also result in less delay in wound healing. Additionally, one would expect fewer complications. Although the complications of traditional laser resurfacing can be reduced by proper postoperative care, [17] these procedures suffer complications even when the laser is used at safe fluences and postoperative care includes the use of occlusive dressings [18].

The most common complication in laser skin resurfacing is persistent erythema [5]. The erythema is due to a combination of epidermal immaturity, reduced melanin absorption of light, reduced dermal optical scattering, and increased blood flow secondary to the inflammatory response [19]. The resolution of the erythema follows the return of the normal epidermis at about 90 days following conventional laser resurfacing. The preservation of the epidermis should, therefore, reduce the amount of erythema and lead to a quicker resolution.

This approach to use a laser for the treatment of fine to medium rhytides is significantly different from laser resurfacing. Although the collagen in the dermis is thermally damaged with the laser and the tissue shows shrinkage, the surface of the skin is not ablated. Additionally, the total thermal damage is deeper. The depth can be controlled, to a certain extent, by the choice of handpiece. The wound repair that follows the laser treatment has shown the creation of new collagen and elastin fibers. Even though there is no direct evidence from these studies that these treatments actually reduce or eliminate rhytides, the histology demonstrates a general improvement in skin tone or skin elasticity and texture.

CONCLUSIONS

Preliminary investigations indicate that lasers can be used to treat solar elastosis in skin while preserving the epithelial layer. The preservation of the epithelial layer should allow more prompt wound healing and make complicated postoperative wound dressing unnecessary. Our studies of tissue shrinkage and the amount of thermal damage indicate that clinical outcomes similar to carbon dioxide laser resurfacing should result. The method needs to be tested for efficacy and safety at this time.

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